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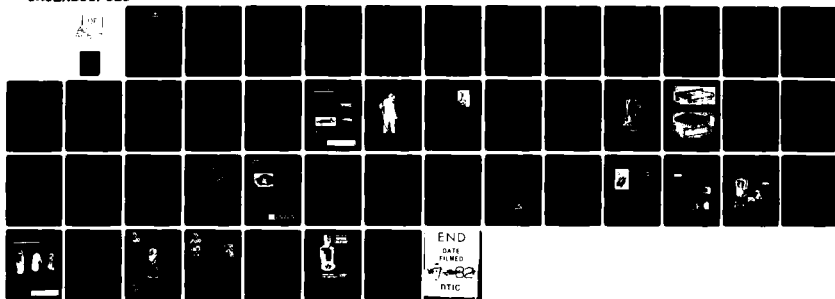
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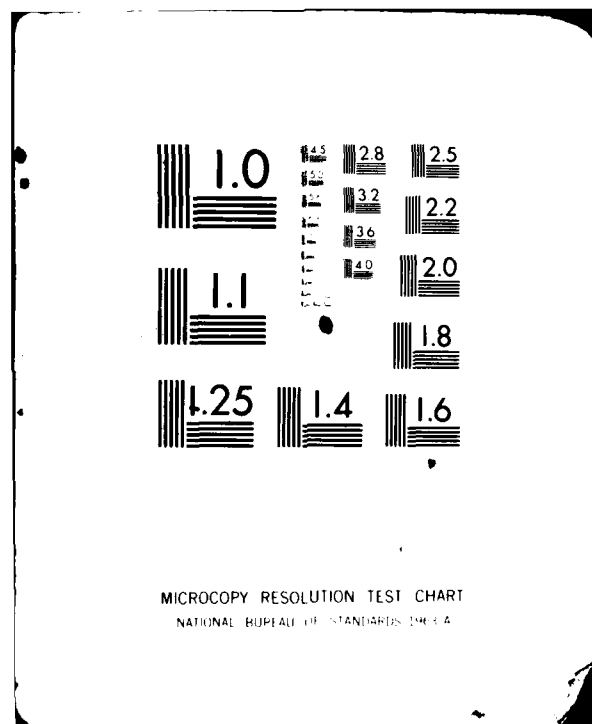
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SUMMARY REPORT

on

INVESTIGATION OF METHODS
OF INSPIRED GAS HEATING

to

NAVAL COASTAL SYSTEMS CENTER
PANAMA CITY, FL 32407

OCTOBER 30, 1981

by

P. S. RIEGEL

BATTELLE
Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201

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Approved by WS Pope and PS Riegel
before mailing

G-7847-0001

xc: DW Frink/JE Sorenson/
CV Robinson/644 Files
WS Pope
PS Riegel (3)
Contracts/RMO

October 30, 1981

Mr. Maxwell W. Lippitt
Code 712
Naval Coastal Systems Center
Panama City, FL 32407

Dear Max:

We are pleased to submit six copies of the Summary Report on
"Investigation of Methods of Inspired Gas Heating". This is intended
to satisfy the delivery requirements of Contract No. N61331-81-M-2369.

In the report we recommended the development of both active and
passive breathing gas heaters of types not presently in existence. We
would be most pleased to assist in such development, should you decide
to undertake it.

If you have any questions regarding this report, please call me at
614/424-4009.

Sincerely yours,



Peter S. Riegel
Research Engineer
Equipment Development Section

Enclosures (6)

PSR:mlg

xc: Supply Officer, NCSC
Mr. Lorne Kuehn, DCIEM
Ms. Jo Rack, Webb Associates



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SUMMARY REPORT
on
INVESTIGATION OF METHODS
OF INSPIRED GAS HEATING

from
BATTELLE
Columbus Laboratories

October 30, 1981

INTRODUCTION

The efficiency and safety of divers are impaired by the cold-water environment. In an effort to combat the effects of cold on the diver the Navy has, for many years, been involved in the design and development of protective garb and equipment for its divers. The types of systems developed have traditionally fallen into two main categories-- active and passive systems. In the active system, heat is supplied to the diver from a heat-generation source, while in the passive system the goal has been to retain the diver's own body heat by means of insulative garments.

As missions get longer and depths deeper, passive systems have been unable to provide the degree of protection required, and the Navy's Diver Thermal Protection Project is presently engaged in the development of an active system.

One area of diver heating in which the problems are still unsolved is that of respiratory gas heating. The thermal losses incurred by the diver in breathing cold, dense gas have been found to be unacceptably high. A number of approaches to respiratory gas heating have been made, and devices are on the market for use by the Navy and industry in solving the problem.

Because Navy efforts in diver heating will certainly extend into respiratory gas heating, this study was contracted to define the present state of the art and to indicate promising avenues of research.

SUMMARY

Existing technology in both active and passive means of divers' gas heating was reviewed. It was found that there are very few firms engaged in the production of hardware for gas heating, but that the active hardware presently produced is generally successful in its operation.

Although some passive devices are marketed for regenerative recovery of exhaled heat, no widely used breathing apparatus today employs regenerative heating, in spite of the obvious advantages.

Specific areas where performance may be improved lie in reducing the heat lost between heater and the diver's head, in the active systems, and in design and construction of a regenerative heat-exchange insert for use in oral-nasal masks in the passive systems.

CONCLUSIONS AND RECOMMENDATIONS

During the course of the work it became obvious that it is possible to provide active heat in all cases to divers' respired gas, and that regenerative heat might profitably be applied to certain configurations. Accordingly it is recommended that further research be undertaken to develop:

- (1) A family of helmet-mounted hot-water heat exchangers, specifically designed to fit each of the full helmets used by the Navy
- (2) A band-mask-mounted hot-water heat exchanger that is similar in principle to (1)
- (3) A simple insert for oral-nasal masks that will perform as a regenerative heat exchanger.

HEAT REQUIRED

The following document, prepared by Webb Associates for NMRDC, establishes the minimum allowable inspired gas temperature for divers at depth. While it is not specifically mentioned, it is assumed that helium is the intended dilution gas.

Rather than summarizing the document, which is already short, we will simply agree with its conclusion, which is that the recommended gas temperatures are probably attainable with suitable heaters.

PHYSIOLOGICAL DESIGN GOALS FOR THERMAL PROTECTION OF DIVERS

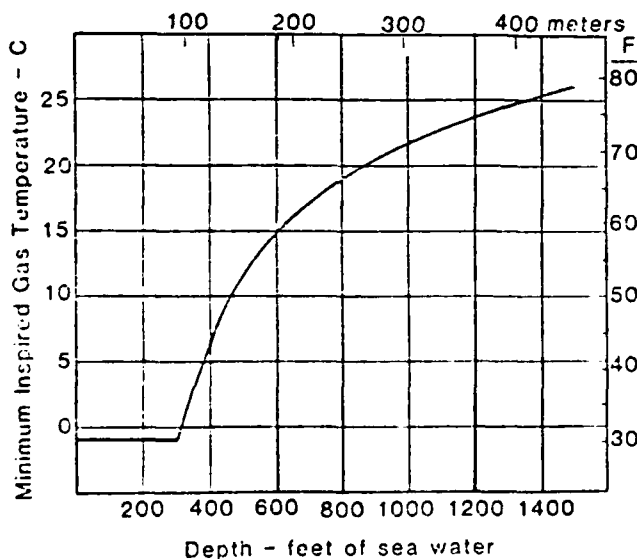
If producing a state of complete thermal comfort in all underwater situations is an unrealistic requirement for protective equipment, limits must be set on the amount of deviation from comfort that can be allowed. Based on present knowledge of physiological and performance effects of cold exposure, a diver or underwater swimmer should be able to perform his assigned tasks and be relatively safe if the following conditions are met. Newly designed equipment should be tested by methods generally accepted in thermal physiology. It is to be emphasized that the purpose of this guidance is to set goals for the design of equipment. It is not intended as an acceptance standard or military specification.

The following four conditions apply concurrently:

1. Maximum net body heat loss (change in enthalpy) of 3 kcal/kg of body weight.
2. Core temperature not lower than 36 C, or a decrease of 1 C, whichever is lower.
3. Mean skin temperature not lower than 25 C, and no individual skin temperature lower than 20 C, except that of the hand, which may go as low as 15 C.
4. Minimum inspired gas temperature as a function of depth as specified by the figure and table below.

When applying heat to a man, either as supplemental heating in cold water or during rewarming of a chilled diver, the following limits apply:

1. No individual skin temperature higher than 41 C.
2. Maximum inspired gas temperature of 45 C for up to one hour and 40 C for indefinitely long exposures.



DEPTH fsw	MINIMUM INSPIRED GAS TEMPERATURE	
	C	F
300	-1.0	30.2
400	6.0	42.8
500	11.5	52.7
600	14.1	57.9
700	17.0	62.6
800	18.7	65.7
900	20.5	68.9
1000	21.9	71.4
1100	22.7	72.9
1200	23.7	74.7
1300	24.6	76.3
1400	25.3	77.5
1500	25.9	78.6

Discussion

Briefly, the design goals are based on the following considerations:

A net heat loss of 3 kcal per kilogram of body weight is tolerable if not incurred as rapidly as, for example, in the sudden immersion of nude men in cold water. A diver wearing inadequate thermal protection might lose this amount of body heat in 1 to 1.5 hours, feel quite cold and shiver strongly. He is warned by these symptoms and terminates the exposure voluntarily. However, 3 kcal/kg lost over three to eight hours causes rather mild core and surface temperature decreases, a mild sense of cold, and little shivering, but this may be the beginning of behavioral changes which could be potentially dangerous. Normalizing the heat loss by body weight is consistent with the observation that large people tolerate far more heat loss than small ones. While net heat loss (heat loss minus heat production) is not a feasible measurement except in special laboratories, it is nevertheless a useful datum for engineering calculations.

A core temperature of 36 C is a conservative low limit for design purposes. Divers whose deep temperatures are no lower than this are not in hypothermia. Medically speaking, hypothermia of significant degree is defined as a core temperature lower than 35 C. The added definition "or a decrease of 1 C, whichever is lower" is included because during the normal circadian rhythm of body temperature it is common for core temperature to fall to 36.5 C overnight. A diver who happens to begin a dive when his core temperature is below 37 C is safe if he loses only 1 C in core temperature—provided, of course, that the low starting temperature was not low as the result of an immediately preceding cold dive.

Skin temperature limits derive from many laboratory and field measurements during various kinds of cold air and water exposures. When the general skin surface is 25 C, there is a strong sensation of cold. Specific areas colder than 20 C are painfully cold, except for the fingers and hands which can usually stay painfree down to 15 C.

The minimum temperatures of breathing gas at depths below 300 fsw, shown in the figure, are based on new experiments from the Navy Experimental Diving Unit. They are temperatures which will produce a drop in core temperature of 1 C in 4 hours, when surface heat loss has been minimized. These gas temperatures are far higher than those previously recommended (the Braithwaite curve), and may thus be conservative. They should nevertheless be achievable with respiratory gas heaters.

A Word About Helium

For many years helium has been unjustly maligned as being a cause of respiratory heat loss. "Helium breathing" is thought to cause excessive heat loss. It is true that, because of its high thermal conductivity, a helium atmosphere removes heat from chamber occupants faster than an air atmosphere does. Chambers with helium atmospheres must be kept at much higher temperatures than those with air atmospheres to avoid chilling of the occupants.

Probably because of this, the idea arose that, because respiratory heat loss was a problem, it was the helium that was the culprit. Nothing could be farther from the truth. In fact, there is no gas that is better than helium for keeping respiratory heat loss to a minimum.

When the diver breathes, he inhales a fixed volume of gas at ambient pressure and temperature, and exhales it at nearly body temperature and ambient pressure. He must give up enough heat during each breath to heat each lungful of gas from ambient to body temperature. The volume that the diver inhales with each breath does not change greatly with depth. Therefore, if he increases his depth he increases the amount of heat he must deliver to the gas he breathes.

The following table shows some gas properties. Of particular interest is the column headed "Heat Capacity per cubic foot". It is seen that, along with argon, helium requires the least heat to increase the temperature of a given volume.

If the toxic effects of air could be magically removed at great depth, it would cause more heat loss than helium. In addition, its much greater density would increase breathing resistance to unacceptable levels.

In short, helium is the ideal gas of choice for reducing respiratory heat loss and is second only to hydrogen for keeping breathing resistance to a minimum.

Table 23. Properties of Gases

Gas	Chemical symbol	Approx molecular weight*	Weight in lb of 1 cu ft at standard atmos pressure and 68 F ^o	Density relative to air	Gas constant, R, in ft-lb per lb, deg F	Specific heat per lb at room temperatures, Btu per lb, deg F		Heat capacity per cu ft at standard atmos pressure and 68 F, Btu per cu ft, deg F		k = c_p/c_v
						c_p	c_v	c_p	c_v	
Helium	He	4.0	0.01039	0.138	386.3	1.25	0.754	0.0130	0.0078	1.66
Argon	A	40.0	0.1037	1.377	38.70	0.124	0.0743	0.0129	0.0077	1.67
Air		29.0	0.07528	1.000	53.30	0.241	0.1725	0.0181	0.0130	1.40
Oxygen	O ₂	32.0	0.08305	1.103	48.31	0.217	0.1549	0.0180	0.0129	1.40
Nitrogen	N ₂	28.0	0.07274	0.966	55.16	0.247	0.1761	0.0179	0.0128	1.40
Hydrogen	H ₂	2.0	0.005234	0.0695	766.8	3.42	2.435	0.0179	0.0127	1.40
Nitric oxide	NO	30.0	0.07788	1.034	51.52	0.231	0.1648	0.0180	0.0128	1.40
Carbon monoxide	CO	28.0	0.07269	0.965	55.19	0.243	0.1721	0.0177	0.0125	1.41
Hydrochloric acid	HCl	36.5	0.09460	1.256	42.41	0.191	0.1365	0.0181	0.0129	1.40
Steam	H ₂ O	18		0.623	85.81	0.46	0.36			1.28
Carbon dioxide	CO ₂	44.0	0.1142	1.516	35.15	0.205	0.1599	0.0234	0.0185	1.28
Nitrous oxide	N ₂ O	44.0	0.1143	1.518	35.12	0.221	0.1759	0.0253	0.0201	1.26
Sulphur dioxide	SO ₂	64.0	0.1663	2.208	24.13	0.154	0.1230	0.0256	0.0204	1.25
Ammonia	NH ₃	17.0	0.04420	0.587	90.77	0.523	0.4064	0.0231	0.0179	1.29
Acetylene	C ₂ H ₂	26.0	0.06754	0.897	59.40	0.350	0.2737	0.0236	0.0185	1.28
Methyl chloride	CH ₃ Cl	50.5	0.1309	1.738	30.62	0.24	0.2006	0.0314	0.0263	1.20
Methane	CH ₄	16.0	0.04163	0.553	96.37	0.593	0.4692	0.0247	0.0195	1.26
Ethylene	C ₂ H ₄	28.0	0.07280	0.967	55.11	0.40	0.3292	0.0291	0.0240	1.22

SOURCE: MARKS' MECHANICAL ENGINEERS' HANDBOOK,
SIXTH EDITION, MCGRAW-HILL BOOK CO.,
INC., 1958

TELEPHONE SURVEY

As part of establishing the present state of the art, a telephone survey of the most obvious sources was made. The following people contributed to the information contained in this report:

Can-Dive (Vancouver, B.C.) - Phil Newton

Comex Houston - Peter Lovie

Comex Marseilles - Yves Guez

DCIEM - Toronto - Dr. Lorne Kuehn

Divex - Harry Kohles

Diving Systems (Santa Barbara) - Kurt Bransford

Diving Unlimited - Phil Phillips

Kinergetics - Tarzana, CA - Tony DeChiro

Oceaneering International (Santa Barbara) - Jarold Bartz

W. J. O'Neill - Consultant

Reimers Consultants - Stephen D. Reimers

Taylor Divers - Winston Chee

Webb Associates - Jo Rack

Westinghouse Annapolis - Richard Usry

PRESENT STATE OF THE ART IN
DIVER BREATH HEATING

Although there have been numerous attempts by the Navy and the commercial diving industry to address the problems associated with the need to provide breath heating, only three firms presently are engaged in the manufacture and sale of diver respiratory heaters.

The Diving Unlimited gas heater is mounted on the diver umbilical. It uses the same hot water to heat both the diver and the gas he breathes. Being a complete in-series system, it eliminates the need for T's and restrictive orifices to control water flow. It uses the incoming hot water to heat the gas flow, which takes very little heat, and passes the hot water on to the suit. The warmed gas passes on from the heater, shielded by a jacket of hot water, to the diver's inlet valve or regulator.

Diving Unlimited also produces a survival breathing apparatus, the "DUI-Hamilton CO₂ Scrubber-Regenerator" intended to maintain life in stranded bells or submarines. This unit, in addition to a chemical scrubber, contains a tiny regenerator in the breathing passage for recovery of exhaled heat.

Kinergetics produces a family of hot-water heat exchangers for use with heated diving suits and breathing equipment. Small, effective and sturdy, they are the best-known of the heaters presently in existence, and have a good reputation in the industry. In Kinergetics' line of stranded bell survival equipment they market a thermal regenerator/ scrubber which is intended to support life for 24 hours when the user is passive and well-insulated. It incorporates a thermal regenerator in the breathing circuit which recovers a claimed 95 percent of the exhaled heat. The regenerator unit is marketed separately as a small cartridge resembling a domed-screen type filter, and can be provided in special mountings to suit the user's requirements.

In addition to Kinergetics and DUI, several heaters have been built, but not developed for the open market. Diving Systems (Kirby-Morgan) had a shrouded side-valve and regulator on their Superlight 17 helmet, and on some helmets which they made for the Canadian Navy, which tempered the cold of the incoming gas. The effect was evidently small, since subsequent models of their helmets have not kept this feature.

Oceaneering International employs a hot-water powered gas heater in the demand regulator of their "Rat Hat", which serves to warm the gas, according to representatives. The exact degree of efficiency is not known, since no formal testing has been done, but warm gas is reported. Built with the assistance of Kinergetics, the unit is a proprietary device of Oceaneering and is not available on the open market as yet.

It was reported by Comex at the 1972 Working Diver Conference that they employed a gas heater on some of their deep dives, although the exact nature of the heater was not specified. The heater appeared to be a backpack hot water heater which warmed the gas before it entered the diver's mask. There did not appear to be any insulation on the gas line from heater to mask.

Comex markets an electrically powered heater, which is further described in a subsequent section of this report.

Battelle constructed a gas heater in 1969 for a Navy 600 foot chamber dive conducted at Duke University. Intended for experimental use with the Mark 9 semiclosed-circuit rebreather, it employed a large flow area filled with spined tubes. The gas exit to the diver's mask was heated with a hot-water shroud. Because of a thermistor failure no hard data were obtained during the dive, but the diver reported that the gas was warm.

METHODS OF RESPIRATORY HEATING

The universal method of providing heat for the diver's gas is to use a branch from the hot water line to the diver's suit as a heat source. The hot water is used in a heat exchanger to heat the breathing gas, and the gas is then led to the regulator or helmet. In order to conserve the heat thus generated in the gas, the gas line is sometimes surrounded with a warm water jacket.

The most obvious disadvantage to the present system is its inefficiency. Although the gas is heated, it must pass through metal valves and passages that are exposed to cold water, which drops the temperature severely. This problem was addressed in the Navy's Band Mask in a tentative manner, with a water jacket on the side valve, but the regulator was not so shielded.

Oceaneering International's "Rat Hat" is the only headgear that heats the gas as it exits to the diver. Although the details of its construction are proprietary information, the demand regulator on the helmet has been constructed so as to receive a direct flow of hot water which heats the inhaled gas. This approach is theoretically the most efficient way to accomplish gas heating, since the gas is heated at its point of introduction to the diver, and has no opportunity to cool before the diver inhales it.

Comex reported in 1972 on their electrically heated diver suit, which maintains thermal balance between the diver and his surroundings. Used with the suit is an electrically powered gas heater worn on the back which provides 1 KW of heat to the gas, reportedly providing the diver with body-temperature gas to 1000 feet depth.

Photographs of the unit show a cylindrical case on the diver's back, with a gas hose emerging at the top which leads to the helmet. It is not apparent whether the gas is kept warm as it proceeds to the helmet from the heater, or whether it is somewhat superheated and then cools down to the desired level by the time it reaches the helmet. This approach could work well in a steady-flow mode, but would be hard to control in a demand mode.

Interfacing With Present Equipment

Most existing breathing equipment has been built for the purpose of supplying gas at ambient temperature to the diver. With the single exception of Oceaneering International's Rat Hat, no breathing apparatus has a built-in heat exchanger at the point of release of the gas to the diver. In all cases the gas is first heated and then cools as it proceeds to the diver. Although the gas lines may be shrouded with hot water, turbulence within the mask or helmet entry point, be it manual valve or regulator, cools the incoming gas severely due to contact with the cold metal.

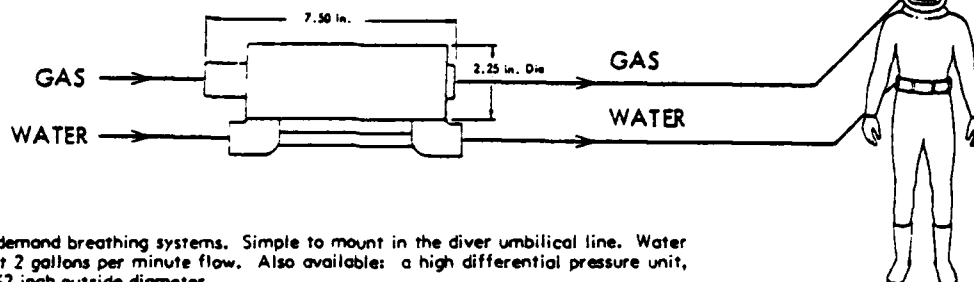
Any single heating system is unlikely to be able to fit more than a few breathing apparatus. Either specific hardware for specific rigs will be required, or a series of adapters.



K¹²INERGETICS INCORPORATED

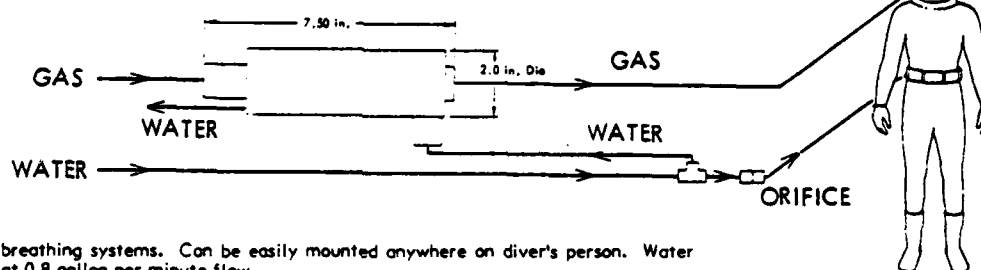
6029 RESEDA BOULEVARD, TARZANA, CALIFORNIA 91356 • (213) 345-2851

SERIES — DEMAND SYSTEM, MODEL 3375-3



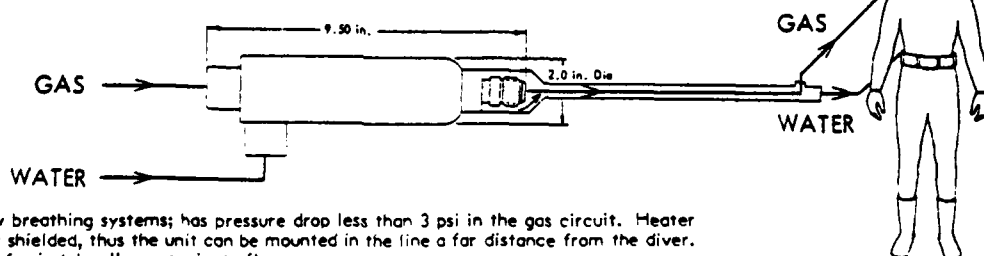
Designed for use with demand breathing systems. Simple to mount in the diver umbilical line. Water pressure drop is 6 psi at 2 gallons per minute flow. Also available: a high differential pressure unit, Model 3375-4 with a 2.62 inch outside diameter.

PARALLEL — DEMAND SYSTEM, MODEL 3370-3



For use with demand breathing systems. Can be easily mounted anywhere on diver's person. Water pressure drop is 25 psi at 0.8 gallon per minute flow.

SERIES — FREE-FLOW SYSTEM, MODEL 3021



For use with free-flow breathing systems; has pressure drop less than 3 psi in the gas circuit. Heater gas supply is hot water shielded, thus the unit can be mounted in the line a far distance from the diver. Water pressure drop is 6 psi at 1 gallon per minute flow.

Kinergetics, Inc. (KI) warrants that its Diver's Breathing Gas Heat Exchangers are free from defects in materials or workmanship for a period of 12 months or 3,000 operating hours whichever occurs first. KI will repair or replace, at its option, any part or subsystem proving to be defective under the following conditions.

Defective units are to be returned to Tarzana, California, freight prepaid; upon completion of repairs, units will be returned to customer FOB Tarzana, California. Alternatively, KI personnel can be dispatched to perform on-site repairs if customer pays transportation to and from Tarzana and living expenses on-site for said personnel as needed.

*Actual Cubic Feet per Minute

Form No. 01-030

January 1979

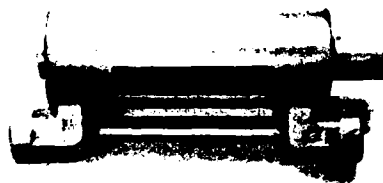
DIVER'S BREATHING GAS HEAT EXCHANGER

3021
3370-3
3375-3
3375-4

**THE ULTIMATE IN CONTROLLED HEAT
EXCHANGER EFFICIENCY AND RELIABILITY!**

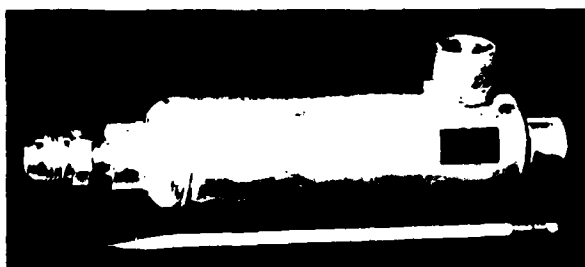
- Small - strong - lightweight (less than 3 pounds)
- Suited to any underwater breathing system
- Can be customized to fit any installation

Gas Flow range to 20 ACFM*
Gas Temperature to 94°F in 35°F sea.



0 in 1 2 3 4 5 6

SERIES - DEMAND



SERIES - FREE-FLOW



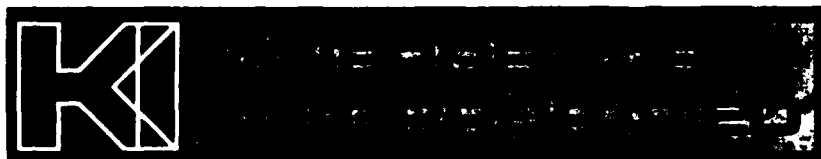
0 in 1 2 3 4 5 6

PARALLEL - DEMAND



The HEX-5 has been proven at 1066 FSW

TECHNOLOGY FOR THE DIVING INDUSTRY



6029 RESEDA BLVD. • TARZANA, CA. 91356 • (213) 345-2851 • TELEX 69-6399

DIVING UNLIMITED GAS HEATER — DUGH

Patent Pending



The DIVING UNLIMITED INTERNATIONAL **DUGH** represents a dramatic advance in simplicity, versatility and cost of any presently available gas heater.

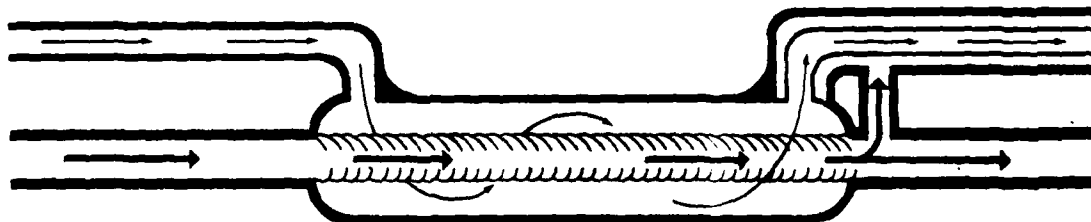
DUGH is the answer to the serious problems of respirator heat loss. **DUGH** is easily installed in any currently known diving system. It can be mounted either on the diver or in his umbilical. **DUGH** uses the same hot water to heat both his breathing gas and him. Being a complete in-series system, it eliminates the need for T's, restrictive orifices, for installation. It also eliminates the need for costly, increased flow rates, and eliminates the safety problem of water loss as would be the case in a parallel system.

DUGH has been tested on saturation dives up to 1000+ feet of 1°C water, with excursion times up to 1 hour.

SPECIFICATIONS

Length	11 1/4 inches
Diameter	1 1/4 inches
Weight	1 1/2 pounds
Gas Fittings	3/8 NPT
Water Fittings	3/8 NPT
Working Pressure	500 psi over bottom
Hot Water Flow	2.0 to 2.5 GPM
Water Pressure Drop	0.5 Pounds
Helium Flow of 5.5 ACFM at 1000 FSW the Gas Pressure Drop is	5 Pounds
*Gas Temp rise —	30°F

*For higher temperature rise, two gas heaters may be used in series.
Catalog #3702-00



COMEX-PRO
TRAVERSE DE LA JARRE
13.275 MARSEILLE CEDEX 2 - FRANCE
TÉL (91) 40.11.70 - TÉLEX : 41.985.



GAS HEATING UNIT

I - PURPOSE

To eliminate the important heat losses which occur in a diver's respiratory system, during deep dives.

It additionally enables the icing-up of the regulator to be avoided and cut out the discomfort caused by breathing cold gases, when diving in very cold water.

II - DESCRIPTION

The COMEX-PRO gas heating unit is made of a cylindrical stainless steel container fitted with an adjustable harness which can be used as a safety lifting device (tensile strength 3000 lbs). It is equipped with a pressure tight plug for power input as well as two fittings for gas inlet and outlet.

III - CHARACTERISTICS

Stainless steel container
 Working pressure : 210 psi
 Maximum depth utilisation : 1,000 feet

Total weight in air : 26 pounds
 In water : slight negative buoyancy
 Overall diameter : 106 mm
 Length of cylinder : 525 mm

Electricity

Gas volume : 3.5 litre
 Input : 24 to 42 volts
 Maximum output : 1 kw for a 36 A.C. input

Gas temperature is electronically regulated at
 $99^{\circ} F \pm 1^{\circ}$ ($37^{\circ} C \pm 2^{\circ}$)
 Resistance : 1.2 ohm.

IV - OPTIONS

The gas heater can be assembled with the COMEX-PRO bail-out system (ref. 206 000) protected by an orange fiberglass shield.

REFERENCE

Gas heater complete : 204 000
 Gas heater with bail-out
 System and shield : 213 000
 Gas heater : 204 100
 Bottle complete : 206 100
 Harness : 206 400
 Fiberglass shield : 213 400

1-2-2. THE RESPIRATORY HEAT LOSS

The respiratory heat loss, which during these past years has been evaluated by several authors, has always been practically neglected due to the relatively shallow depths usually involved in industrial diving operations (less than 400 feet), especially in very cold waters.

This respiratory heat loss consists of:

- 1° - The necessary heat for humidifying the breathed gas, which has been dried in the compression process, which can be evaluated at 1.77 watt per liter per minute of respiratory volume.
- 2° - The heat for warming the breathed gas from ambient temperature to approximately the normal body temperature. (In reality, the temperature of the exhaled gas slowly decreases with the ambient temperature.)

This heat loss (Hl) is proportional to absolute ambient pressure, to the difference between body and ambient temperatures, and to the respiratory volume.

With a helium-oxygen mixture, it can be evaluated at:

$$Hl = .0136 \times P \times \Delta t \times V \quad \text{watts}$$

where:

P is the absolute pressure in atmospheres

Δt is the temperature gradient in degrees C.

V is the respiratory volume in liters per minute.

The total respiratory heat loss is, then, given by Figure 1.

For instance, a diver at 250 meters (840 ft.) depth, in a 12°C. (53°F.) water would lose 420 watts for a 40 liters (1.4 CFM) per minute respiratory volume (which is a normal volume under working conditions).

This represents about 60% of his metabolic heat production which is about 17.4 watts per liter per minute of respiratory volume.

In arctic conditions, the diagram shows the metabolic production would be completely balanced by the respiratory heat loss at a depth of approximately 280 meters.

A greater heat loss cannot be tolerated, and adequate compensation by heating the suit is impractical because dissipation of heat from the suit is limited by the comfort of the diver.

SOURCE: "DEEP DIVING AND COLD WATER - SOME PRACTICAL RESULTS" BY ALAIN JEGOU (COMEX) - PROCEEDINGS, "THE WORKING DIVER", FEB 22-23, 1972, BATTELLE, COLUMBUS, OH.

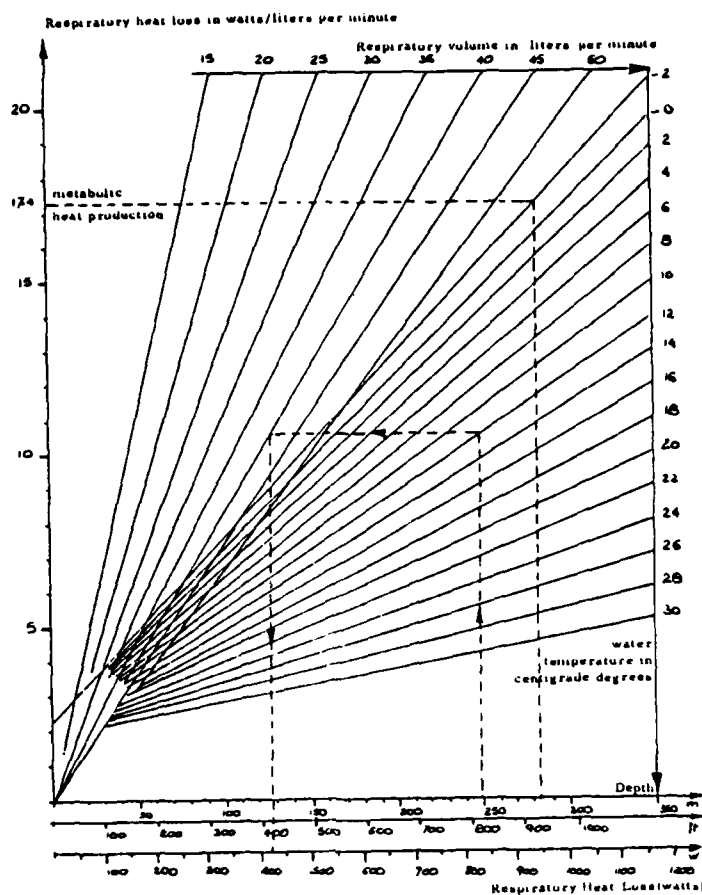


FIGURE 1. RESPIRATORY HEAT LOSS

This shows the absolute necessity of heating the breathing gas of the divers for completing industrial diving operations deeper than about 400 feet.

This has led COMEX to design an electrical, electronically regulated gas heater.

This individual unit worn on the back of the diver (see Figure 2) is powered from the P. T. C. through the diver's umbilical. Its maximum power capability is 1 kilowatt, thus permitting dives down to 1000 feet in arctic conditions. (See Figure 1.)

The temperature of the inhaled gases is maintained at 37.2°C . (98.5°F . \pm) by means of a specially designed heating and regulating system independent of depth, water temperature, mixture, or diver's breathing rate.

This piece of equipment totally stops respiratory heat loss, thus providing the diver with unequalled comfort and working performance.

Much improvement certainly can be made in the methods and equipment in use, and this is one of our main concerns within COMEX's 1972 Research and Development Program.

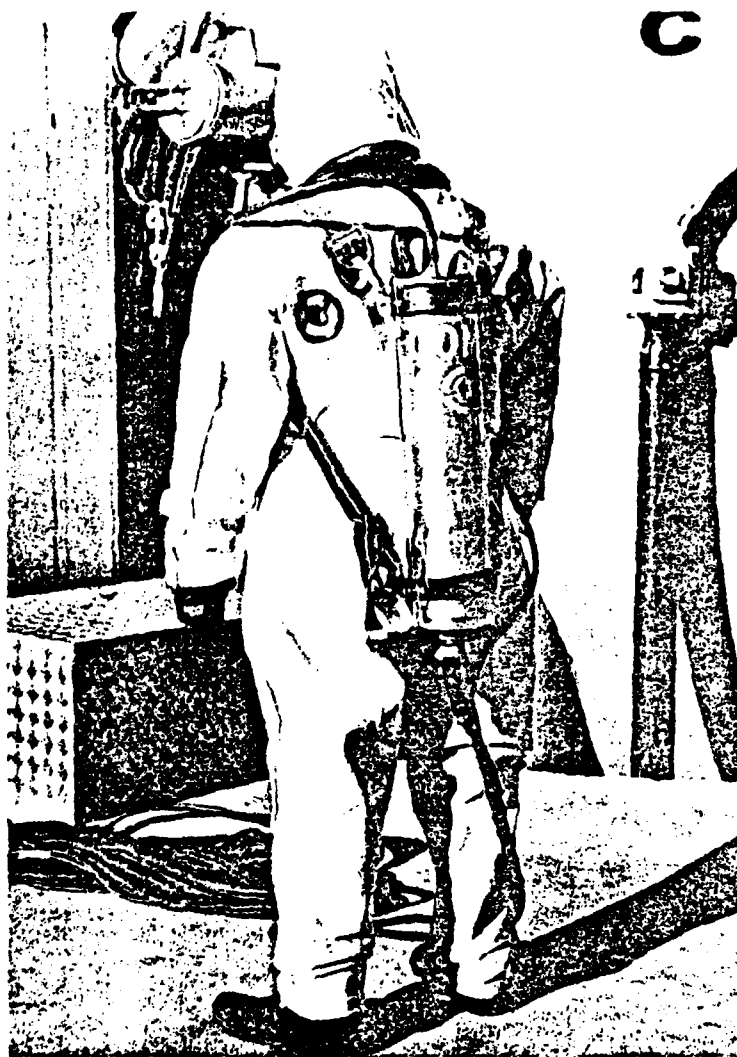
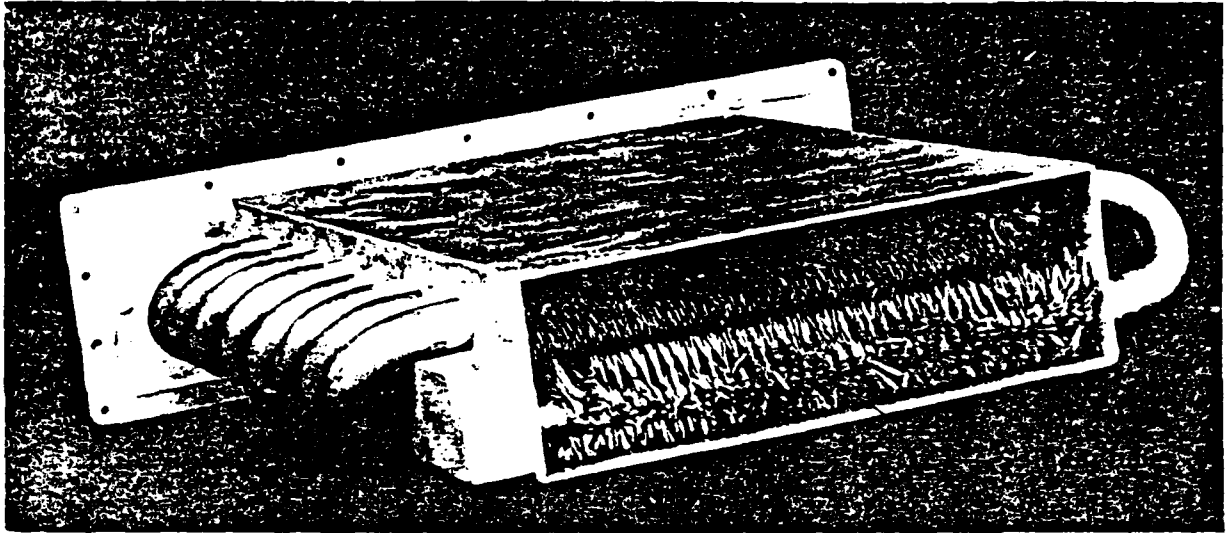
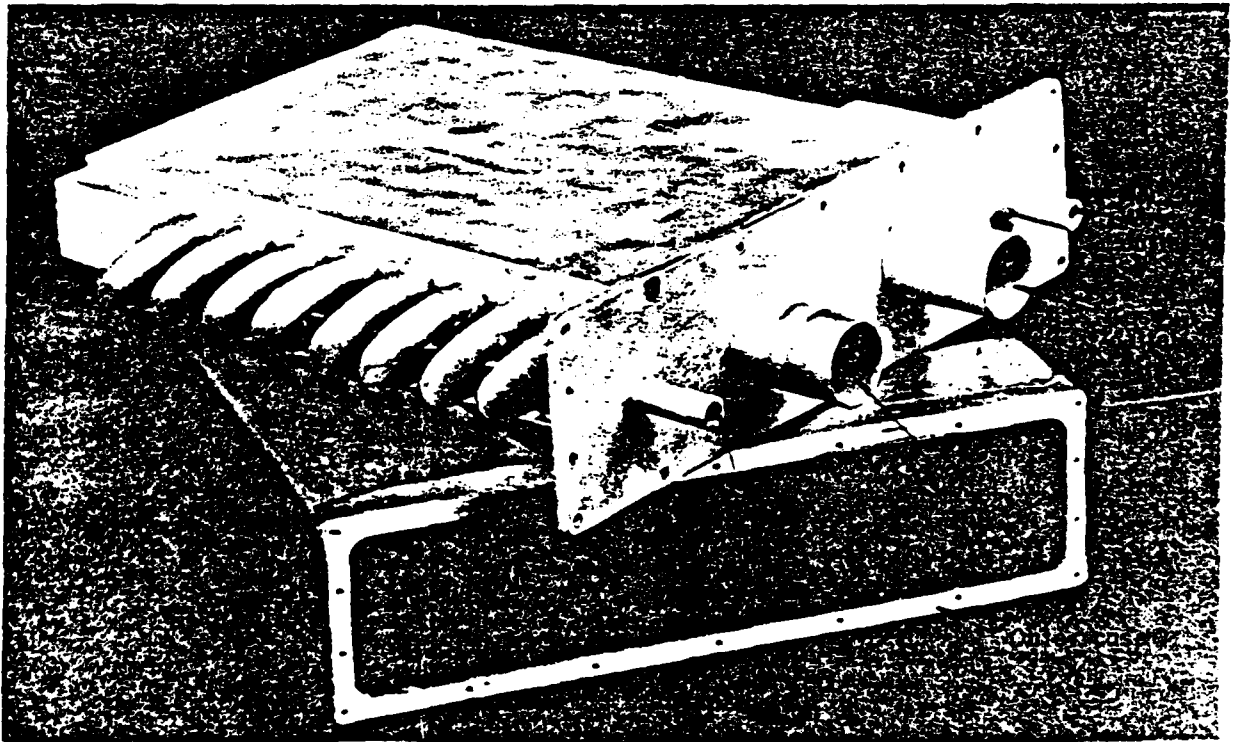


FIGURE 2. DIVER EQUIPPED FOR COLD WATER



C6707

FIGURE 4. HEATER DISASSEMBLED



C6708

FIGURE 5. HEATER DISASSEMBLED

SOURCE: "DEVELOPMENT OF AN EXPERIMENTAL BREATHING GAS HEATER" PREPARED BY
BATTELLE UNDER CONTRACT NO. N00014-66-C-0199, SEPT 24, 1969

Breathing Apparatus

There are four distinct types of breathing equipment that the diver may use. They are:

- (1) Full helmet
- (2) Face mask
- (3) Mouthbit
- (4) Articulated suit.

Full Helmet

The full helmet is used with a steady flow of gas, which may come from a compressed-gas supply, from a push-pull pump, or from a backpack-mounted, semiclosed-circuit, ejector-driven recirculating apparatus. It may be used with a neck dam, or it may be connected to the diver's dress by a neck ring.

In the full helmet there is generally no direct couple between the gas supply and the diver's respiratory passages. Instead the incoming gas mixes with the gas already in the helmet and is breathed by the diver. Flow rate is such that the exhaled carbon dioxide is sufficiently diluted to provide a tolerable level for breathing. Generally an effort is made to duct the incoming gas in such a way as to provide a fresh flow near the diver's face, and to remove the exhaled gas at a point away from the face, in an effort to create a gradient of fresh gas, so that the diver breathes gas that is, on the whole, fresher than the average helmet content. Because the gas flow is generous, there is no need for an oral-nasal mask within the full helmet, and this is much appreciated by the users.

Of the first three types of breathing equipment, the full helmet has the least breathing resistance.

Face Mask

Face masks, typified by the many variations of the Band Mask, fit closely around the periphery of the diver's face and are

held in place by rubber straps. They typically are equipped with a gas control valve, located on the right side of the mask, and with a demand regulator, located on the front. By manipulation of the gas control valve, or "side valve", the diver can provide himself with a constant stream of fresh gas, or he may breathe solely in the demand mode, or he may combine the two modes.

In a band mask the diver wears an oral-nasal cup, which serves to direct the fresh gas from the supply to his breathing passages, and to separate the breathing space ("dead space") from the main volume of the mask. Free-flow gas enters the mask outside the oral-nasal cup and is drawn in through a check valve. Exhausted gas leaves through a check valve at the bottom of the mask, and through the check valve in the demand regulator. These valves, being located low in the system, serve to drain off any water that may accumulate. Because incoming gas enters outside the oral nasal cup, and is directed across the faceplate, the tendency for the mask to fog from excess humidity is minimized.

Several attempts have been made to provide the band mask user with warm gas. The Navy provided a few band masks in which the diver wore a back-mounted hot-water gas heater. The warm gas left the heater via a hose that led to the side valve. In order to prevent heat loss from the warm gas hose, the warm water leaving the heater was ducted around the gas hose through a larger hose which also led to the side valve. A shroud around the side valve kept it surrounded with warm gas. The resulting gas flow from the side valve was warm. In the free-flow mode, entering gas was warm, but when the unit was used in the demand mode, significant heat loss was experienced through the metal tube leading from the side valve to the demand regulator, and through the demand regulator itself.

The degree of effectiveness has not been well-documented, and no band masks today employ this system of gas heating.

Mouthbit

The mouthbit is used when it is necessary to couple the diver directly to his source of gas in order to use him as a pump to

draw gas from the source. It is used in open-circuit scuba and in closed and semiclosed circuit UBA as well. Because of the inevitable fatigue caused by long use of a mouthbit, and because effective voice communication is limited, mouthbit UBA are not used for long-term dives or for working dives requiring communication.

Because the use of mouthbit UBA is generally limited to shallow dives, no great effort has been expended on gas heating, because at shallow depths there is no problem of respiratory heat loss. Nevertheless, one intriguing approach to providing respiratory heat for the users of open-circuit scuba has been reported. Developed by workers at Scripps, the device employs a catalyst bed located in the line leading from the first stage to the second stage of the demand regulator. Hydrogen is added to the breathing air, at 1-1/2 percent, which is well below the lower explosive limit. When the diver inhales, the hydrogen is burned in the catalyst bed, producing only heat and moisture. The warm gas thus generated is then inhaled by the diver. Although no data are available, it has been mentioned that the gas is warm and helps increase dive duration in cold water.

Although the oxygen content of the air is fractionally reduced by this method, it has no effect on the diver, since at more than a few feet of depth the oxygen partial pressure is greater than at the surface. Although it is possible that the resulting higher nitrogen partial pressure may affect decompression, the increase is so slight as to be, in all likelihood, negligible.

Articulated Suit

These hard-shell suits, while used for extremely deep dives, maintain the diver in a surface-pressure air atmosphere, and no problem of respiratory heat loss exists. They will not be considered further in this discussion.

Regenerative Heating

Ever since the late 1960's, when the potential problems of respiratory heat loss began to be recognized, attempts have been made to

address the problems of heat loss. The most attractive principle requires no outside power, because the heat in the diver's exhaled breath is used to heat the next incoming breath.

If a heat exchanger is located in an oscillating flow of gas, and if the temperature of the exchanger is uniform throughout, the average temperature of the exchanger will be the average temperature of the two parts of the gas flow. If a diver is inhaling gas at 30 F and exhaling at 90 F, the mean temperature of the heat exchanger will be 60 F. The inhaled gas will be warmer at the beginning of inhalation and colder at the end of inhalation, but with proper design of the heat exchanger will not vary substantially from 60 F. However, if a number of such exchangers are placed in series, the mean temperature of any single unit will be that of the mean gas temperatures entering from the exchanger on either side. If enough exchangers are mounted in series, the cold end of the unit will stay cold, and the warm end will remain warm, and the temperature gradient within the unit will shift back and forth as respiration proceeds.

The earliest such device of which we are aware was reported by Fischel in 1970. The device is simply a series of fine screens mounted within the diver's mouthpiece, which heat up during exhalation and cool down during inhalation. The device, it was reported, delivered warm, humid gas to the diver at little penalty in terms of breathing resistance.

All of the presently-available regenerative heaters use the principle reported by Fischel. They all use a short tube which is fitted with metal screens or fibers to recover and redeliver the heat generated by the diver during respiration.

Another way to visualize the operation of a regenerative heater is to consider that the diver is breathing in and out through a long, perfectly insulated metal pipe. After respiration has been going on for a while, a temperature gradient will develop along the pipe, warm at the diver end and cold at the water end. The mean temperature of the pipe will be that of the mean of the two flows, but the gas will become warmer from the interaction with the pipe walls as it enters, and the exhaled gas will cool as it approaches the water end of the pipe. This type of

system would, of course, be unsuitable because of excessive dead space and flow resistance, but it serves to describe the principle.

The fitting of many small heat-exchange elements in series results in a compact unit which has neither excessive breathing resistance nor great dead space.

Although the principle of regenerative heating is sound, it has not been employed to any significant degree, because the present regenerators are best suited to use in a mouthpiece, and mouthpieces are used only in shallow-water breathing apparatus, where the problem of respiratory heat loss is not severe. No regenerative device has yet been devised to fit within the small confines of an oral-nasal mask, or in a helmet.

Although the benefits of regenerative heating have been known for some time, they possess a drawback that has so far not been overcome. They have a tendency to get plugged up. Because they consist of many small gas passages surrounded by metal, water, phlegm, spit and mucus emanating from the diver or the environment collect on the surfaces of the heat exchange elements and reduce the effective flow area, increasing breathing resistance.

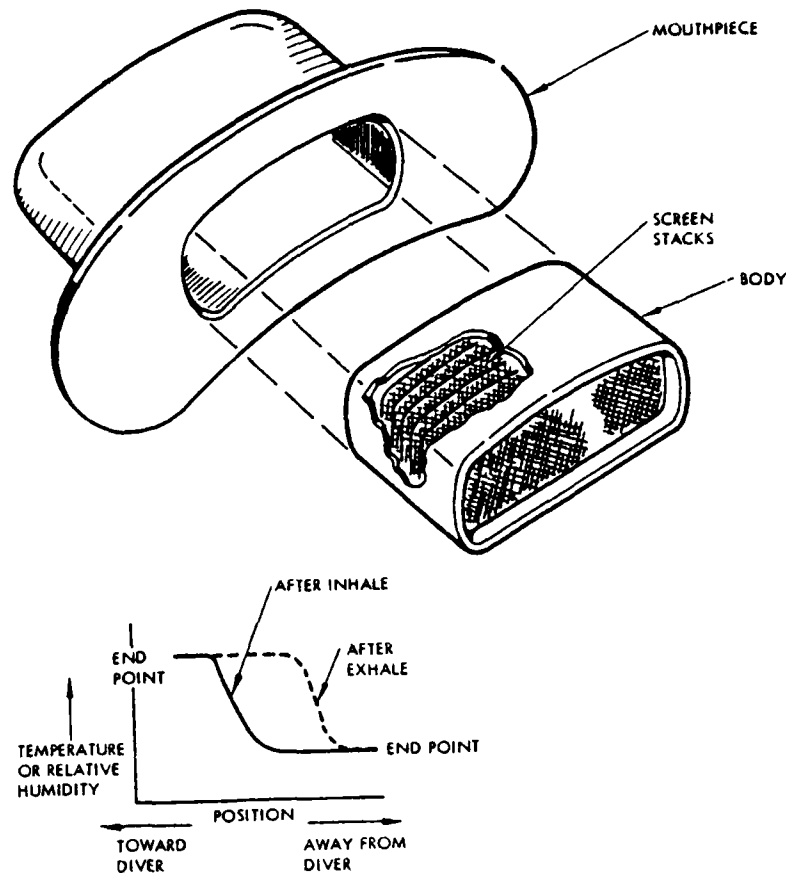


Figure 7 Mouth Piece Regenerator

Other examples of heat transfer and thermodynamic considerations which may prove useful in the diver's breathing apparatus are not necessarily cryogenic in nature. One such device is the thermal and humidity regenerator placed in the diver's mouthpiece. Figure 7 illustrates just such a device consisting of a short stack of fine wire cloth or a finely divided porous hygroscopic material. The function this simple device serves is to conserve the temperature and humidity contained in the respired gas being repeatedly exchanged by the diver. As shown in the temperature profile of Figure 7, heat contained in the exhaled gas is deposited in the regenerator and subsequently recovered from the regenerator upon the following inspiration. Similarly, water vapor condenses in the regenerator and is reabsorbed by the inhaled gas. The end points of the regenerator typically remain fixed on the temperature and saturation diagram. The gradient between these end points shifts toward one or the other, respectively, depending upon which part of the cycle, i.e., exhale or inhale, is operative. The entire structure is never totally cooled or warmed but fluctuates between the two conditions when properly designed for the cycle in question. Thus, as gas progresses in one direction or the other it is forced to follow the temperature and humidity profile that has been set up in the regenerator. Efficiencies in excess of 90% are readily obtained with properly designed but, nevertheless, simple regenerator structures and materials. A typical mouthpiece regenerator has been demonstrated which operates under 50°F ambient water temperature conditions and delivers gas in excess of 90°F and 90 percent relative humidity at a pressure drop of 0.1 inches of water. This obviously mitigates the respiratory heat and water loss from the diver and adds significantly to his comfort.

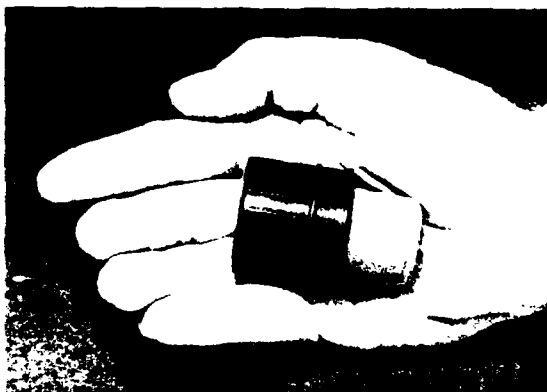
SOURCE: "CLOSED CIRCUIT CRYOGENIC SCUBA" BY HALBERT FISCHER,
PROCEEDINGS, "EQUIPMENT FOR THE WORKING DIVER",
FEBRUARY 24-25, 1970, BATTELLE, COLUMBUS, OH

THERMAL REGENERATOR

26

MPR-2
T-600

MPR-2 BREATHING REGENERATOR FOR CONSERVATION OF RESPIRATORY HEAT LOSS IN UNDERWATER USE



Type T-600 — For use by working divers on Hell-Ox to 600-foot depths.

- Passive conservation of respiratory heat loss.
- Passive protection in bell and chambers if heating is lost.
- Available in special mounting to suit your requirements.

The KI MPR-2 is a unique device used to conserve the warmth and moisture in a diver's breath. No outside source of heat is required. These functions are performed by use of a thermal regenerator conceived and designed for this particular mission. The proprietary techniques* employed by KI enable the conservation of heat and moisture to be carried out at a very high level of efficiency — as much as 95% of expired heat and moisture can be saved.

A thermal regenerator acts like a two-way "heat sponge". As the diver exhales through the regenerator packing, his breath is cooled and dried on its way to the surrounding environment. Subsequent inhalation brings new breathing gas back through the packing. The new gas is warmed and moisturized in the reverse manner to almost the same conditions as the original exhaled breath. Very little pressure drop is encountered through this process.

Various models of the Type T are present in use and available. A configuration to fit your specific diving system and mission is a simple matter of packaging design.

* Patent No. 3,747,598. Other patents pending.

Nov. 1979

TECHNOLOGY FOR THE DIVING INDUSTRY



6029 RESEDA BLVD. • TARZANA, CA 91356 • (213) 345-2851 • TELEX 69-6399
11 GREENFERN PL. • MASTRICK, ABERDEEN, SCOTLAND • (0224) 681020 • TELEX 739675

Of particular assistance in the search for existing technology was Dr. Lorne A. Kuehn of the Defence and Civil Institute of Environmental Medicine, in Toronto. He has, over the years, had a sustained interest in the subject of respiratory heat recovery, and has amassed a collection of patents and information on the subject. In response to our call he was kind enough to send the letter that is reproduced in the following pages.



1415-1 (BIO)
9510-1

17 September, 1981

Dr. Peter Riegel
Battelle Institute
505 King Avenue
Columbus, Ohio 43201
U.S.A.

Dear Peter:

In response to your telephone call last week, several research groups are involved in the basic and applied research of reclamation of diver's respiratory heat. One of the foremost groups is that headed by Dr. Charles Johnson in the Department of Mechanical Engineering at Duke University. Other groups exist at the United States Navy Experimental Diving Unit in Panama City, Florida (contact Dr. Thalaman), and at the United States Navy Medical Research Institute of Bethesda, Maryland (contact Dr. Chris Greene). Internationally, some work is carried out at the Admiralty Marine Technological Establishment in Portsmouth, England (contact Dr. Allan Thornton) and the Laboratoire de Médecin Aerospatiale in Bretigny-Air, France (contact Dr. Charles Boutilier). I would also refer you to Dr. Paul Webb Associates, Yellow Springs, Ohio, for further information on other research groups.

As to technology, a number of devices have been patented to reclaim both heat and water from the expired breath. Among these the following patents warrant consideration:

<u>Inventor</u>	<u>Patent Number</u>	<u>Date Patent Issued</u>
W.H. Lehmberg	US 2,269,461	June 13, 1942
Phillips	US 2,610,038	Sept 1952
R.G. Bartlett, Jr.	US 3,099,987	Aug 6, 1963
G.E. Gross	US 3,107,669	Oct 22, 1963
P.A. Klauswitz et al	US 3,142,549	July 28, 1964
W.D. McCoy	US 3,326,214	June 20, 1967
R.J. Barghini et al	US 3,333,585	Aug 1, 1967
W.W. Weese	US 3,491,754	June 27, 1970
K.W. Cowans	US 3,747,598	July 24, 1973

In addition, I have enclosed a copy of a patent of my own contribution to this field, which is more efficient than some of the others mentioned above.

.../2

DEFENCE AND CIVIL INSTITUTE
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M3M 3B9

At least two commercial suppliers of passive respiratory heat exchangers exist. Both are supplying the diver technology market and they are Kinergetics, Inc. of California and R.W. Hamilton of Tarrytown, New York. I am aware of at least one other past supplier of a device for Arctic use but the company involved no longer exists.

The use of active techniques to reduce respiratory heat loss suffers from the expense associated with supplying a device with the necessary heat from an external power source. Furthermore, the technology required for thermal control of such apparatus is complicated and constitutes an extra mass problem and burden.

The passive devices proposed up to now have not met with much commercial success for a variety of reasons such as extreme bulkiness, heavy weight, many moving parts, tortuous pathways which cause extra energy expenditure by the user during inhalation and exhalation, tendency of the air passages to become occluded under operating conditions, corrosion and maintenance problems, low efficiency and high cost.

I hope that this material will prove useful to you and I would be pleased to correspond further on this topic.

Sincerely,



Lorne A. Kuehn, Ph.D.
Director, Biosciences Division
for Chief

Enclosure: 1

United States Patent [19]

Kuehn et al.

[11] 4,201,206

[45] May 6, 1980

[54] HEAT RECEIVER FOR DIVERS

[75] Inventors: Lorne A. Kuehn, Downsview; Louis A. Pogorski, Toronto, both of Canada

[73] Assignee: Her Majesty the Queen in right of Canada, as represented by the Canadian Minister of National Defence, Ottawa, Canada

[21] Appl. No.: 943,491

[22] Filed: Sep. 18, 1978

[51] Int. Cl.² A62B 7/00

[52] U.S. Cl. 128/201.13; 165/DIG. 17; 165/65

[58] Field of Search 128/212, 142 R, 147, 128/142.2; 165/4, 65, DIG. 17

[56] References Cited

U.S. PATENT DOCUMENTS

3,747,598	7/1973	Cowans	128/212 X
4,090,513	5/1978	Togawa	128/212
4,136,691	1/1979	Ebeling et al	128/212

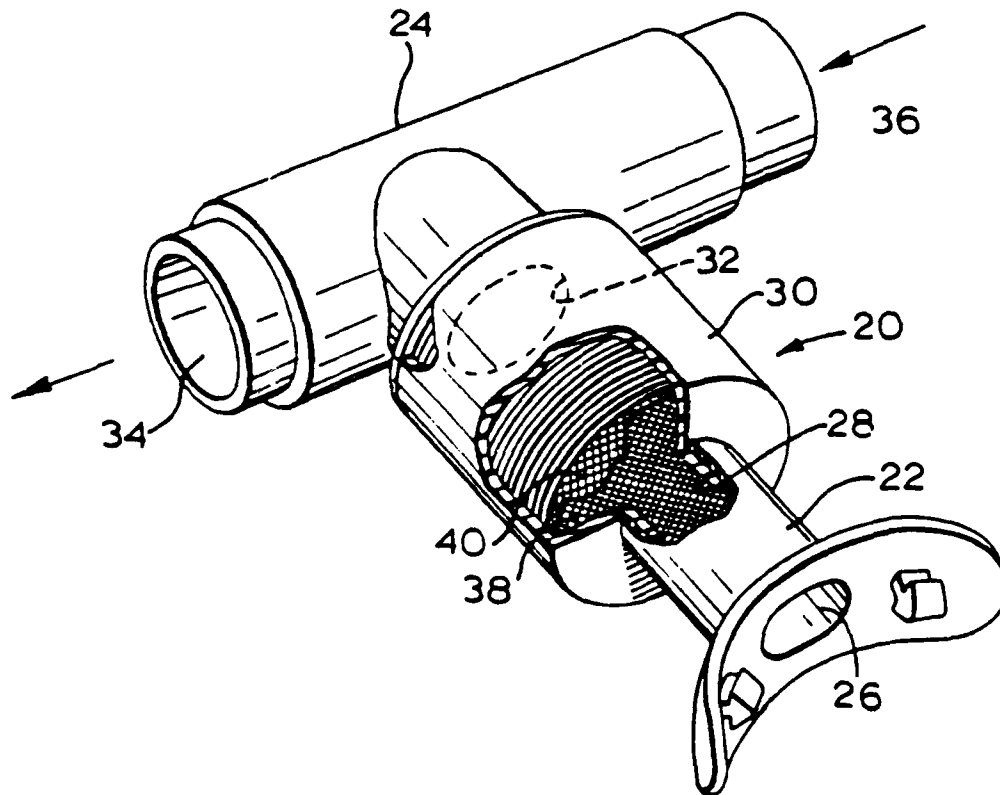
Primary Examiner—Henry J. Recla

Attorney, Agent, or Firm—Hirons, Rogers & Scott

[57] ABSTRACT

A heat receiver is provided comprising a housing through which the breathing mixture passes in one direction and through which the exhaled breath passes in the opposite direction. The housing contains heat conductive elements through which the breathing mixture and exhaled breath pass and spacers positioned one between each pair of adjacent heat conductive elements. The spacers are poor heat conductors and non-hygroscopic to minimize moisture retention. In use, exhaled breath warms the heat conductive elements sequentially so that each element will be slightly cooler than the last element exposed to the exhaled breath. There will be minimal heat stored in the spacers and the moisture content of the exhaled breath tends to be carried through the device so that upon drawing breathing mixture through the device a substantial part of the sensible heat originally in the exhaled breath will be reclaimed by the breathing mixture. The latent heat originally in the exhaled breath will be lost.

4 Claims, 5 Drawing Figures



Coal Mine Self-Rescue Breathing Apparatus

Although the principle of regenerative heat exchange has been demonstrated in several commercial breathing devices, mentioned earlier, the most widespread application of the principle occurs in the field of mining. Every coal miner in the United States carries on his belt a sealed canister containing a breathing apparatus. Called a "self-rescuer", it is provided for those rare occasions when the miner is threatened by a fire in the mine, and it is intended to allow him to reach safety although surrounded by smoke.

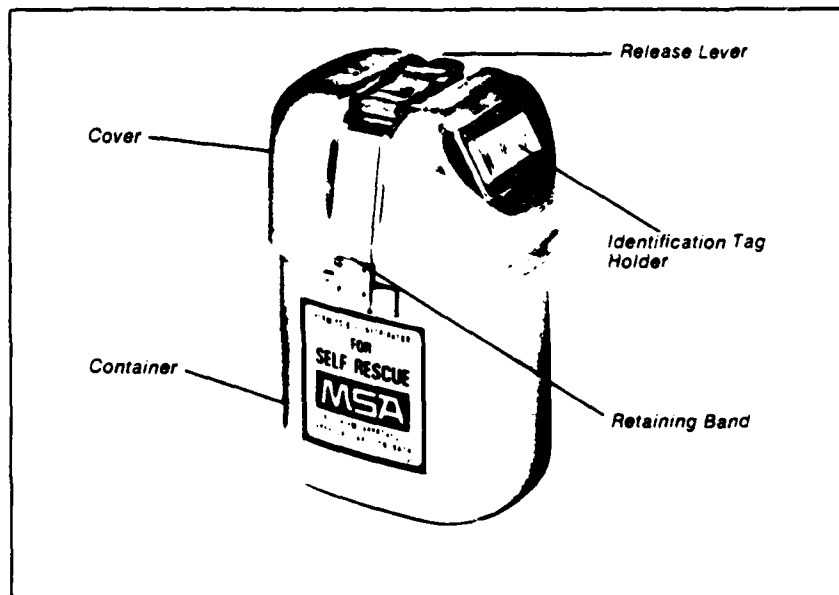
A principal hazard to the miner in a fire is carbon monoxide. The self-rescue breathing apparatus reduces this hazard by removing CO from the inhaled gas. Good for one hour at 1 percent CO, the apparatus is a simple Hopcalite catalyst bed mounted on a mouthpiece. Hopcalite, a mixture of manganese oxide and copper oxide in pelletized form, transforms CO to CO₂, producing heat when it does so. Because the CO₂ is not toxic at low levels as is CO, the user simply inhales the produced CO₂ without harm. Exhalation proceeds through a check valve.

Because the heat produced by the chemical reaction can rise to objectionable levels, a regenerative heat exchanger is used to cool the inspired gas. Consisting of a simple pad of compressed stainless-steel wire, it is located just outboard of the mouthpiece itself, and inhalation and exhalation alternately heat and cool the pad, thus tempering the effect of the hot gas breathed by the miner.

Although obviously not directly applicable to the problem of diver respiratory heating, the device is compact, well-designed, simple and cheap, and shows what can be done when competence is applied to the problem.

The device is manufactured by Drager and is distributed in the United States by Mine Safety Appliances, Inc.

Self-Rescuer Respirator W65



Application

The W65 Self-Rescuer Respirator provides emergency respiratory protection against carbon monoxide gas resulting from underground fires or explosions. **A one-time-use device for escape purposes only**, it provides respiratory protection against carbon monoxide in otherwise respirable air; it should not be used in atmospheres containing less than 19.5 percent oxygen or in atmospheres containing other toxic gases and vapors.

Description

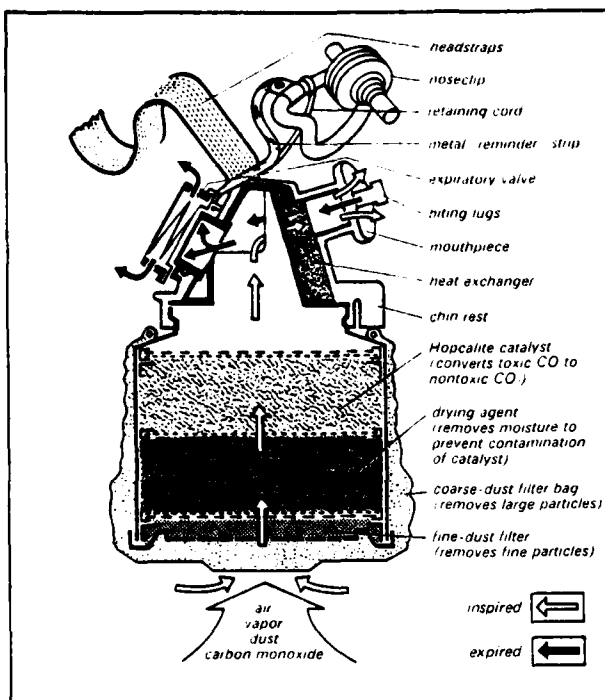
The Self-Rescuer uses the oxidation catalyst Hopcalite® to convert the toxic carbon monoxide to nontoxic carbon dioxide. The filter unit consists of an outer coarse-dust filter and an inner fine-dust filter to remove dust particles, the Hopcalite catalyst, and a drying agent to protect the Hopcalite from moisture.

The respirator exceeds NIOSH/MSHA specified service-life requirements of 60 minutes against 1% carbon monoxide in air (25 C, 95% RH), at a continuous flow rate of 32 liters per minute. (Tests at 2% CO showed that the Self-Rescuer will still afford protection but that the increased heat of reaction will eventually force wearer to retreat to an atmosphere with a lower CO concentration.) Heat buildup caused by the oxidation reaction is inherent in the operation of a self-rescue unit of this type, but an integral heat exchanger in the W65 Self-Rescuer reduces the temperature of the inhaled air to a bearable level. To protect the filter bed from moisture contamination, expired air is passed back through the heat exchanger and

out through the spring-loaded mica disc expiratory valve. Excess saliva is also expelled through the expiratory valve.

Protected in a stainless steel case, the W65 Self-Rescuer has a positive, hermetic seal and has indefinite shelf life; it can be carried by personnel or mounted on moving equipment for a period up to five years without maintenance (however, if it has been used or the seal is broken, it must be replaced with a new factory-sealed unit).

The entire assembly weighs approximately 1000 grams (2.2 lb), and can be carried comfortably on the hip by means of an integral belt loop 1¾ in. wide (an accessory leather or neoprene holster is available to adapt to belts up to 2½ in. wide).



Important

The W65 Self-Rescuer is an air-purifying device designed to protect the wearer from toxic carbon monoxide. It does not supply oxygen but functions to oxidize carbon monoxide to carbon dioxide with a resulting heat of reaction. Therefore, when the Self-Rescuer is worn in an atmosphere containing carbon monoxide, the air entering the wearer's mouth will be hot and dry. The temperature of the inhaled air is dependent upon the concentration of carbon monoxide—the higher the concentration, the higher the temperature. The very presence of heat indicates that carbon monoxide is present in the air being drawn into the Self-Rescuer, and the Self-Rescuer should never be discarded because of discomfort from hot, dry air. All air must be drawn through the Self-Rescuer.

The W65 Self-Rescuer contains a heat exchanger to reduce the discomfort caused by high concentrations of carbon monoxide. For example, tests at 1.5% carbon monoxide showed that the heat exchanger will effectively reduce the temperature of inhaled air from approximately 300 F to 150 F. Though uncomfortable, one can tolerate even higher inhaled air temperature since the respiratory system itself is an effective heat exchanger. The importance of training workers to use the nose clip at all times and to breathe through the Self-Rescuer until they reach fresh air is emphasized by the fact that a carbon monoxide concentration of 0.5% (5000 ppm) can cause rapid collapse, unconsciousness, and death within a few minutes. It is far better to be alive with a hot or even blistered mouth than to be overcome or killed by carbon monoxide. Do not sneak a breath or two of relatively cool air into the mouth by opening the lips.

Note: For further cautions and instructions—including the importance of training in the use of this device—refer to the USBM "Handbook for Miners," and USBM Instruction Guide 2, "MSA W65 Self-Rescuer."

Approvals and standards

The Self-Rescuer Respirator W65 is approved by the Mine Safety and Health Administration (MSHA) and National Institute of Occupational Safety and Health (Approval No. TC-14G-82) for self-rescue from carbon monoxide. Previously assigned Bureau of Mines Approval No. 14F-76.)

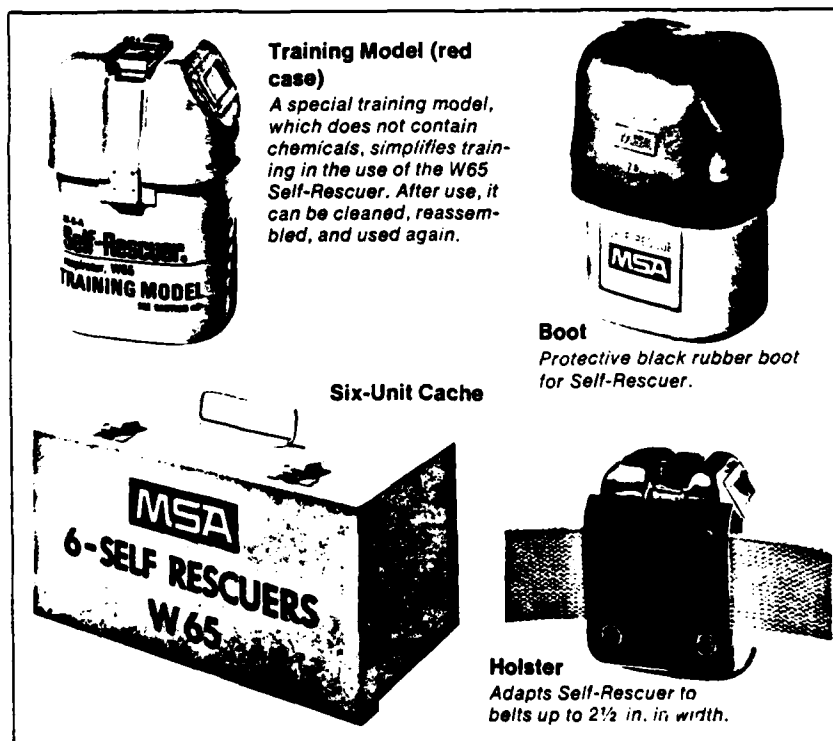
Ordering information

Catalog numbers

- 455299** MSA Self-Rescuer Respirator W65, ea; complete in carton
- 461100** MSA Self-Rescuer Respirator W65, with protective boot and neoprene holster
- 455647** Cache assembly, six Self-Rescuers in metal case
- 455568** Cache case only
- 455535** Leather Holster to adapt Self-Rescuer to belts up to 2½ in. in width
- 460027** Neoprene Holster to adapt Self-Rescuer to belts up to 2½ in. in width
- 449428** Boot, protective, for Self-Rescuer
- 455696** Self-Rescuer Training Model

Note: This Data Sheet contains a general description of the MSA Self-Rescuer Respirator W65. While uses and performance capabilities are described, under no circumstances should it be used until the instructions, labels, or other literature accompanying it have been carefully read and the precautions therein set forth are understood and followed. Only they contain the complete and detailed information concerning this product.

Accessories



Training Model (red case)

A special training model, which does not contain chemicals, simplifies training in the use of the W65 Self-Rescuer. After use, it can be cleaned, reassembled, and used again.

Six-Unit Cache

Boot

Protective black rubber boot for Self-Rescuer.

Holster

Adapts Self-Rescuer to belts up to 2½ in. in width.

MSA

Mine Safety Appliances Company
600 Penn Center Boulevard
Pittsburgh, Pennsylvania 15235

At your service 20 branch offices in the United States
MSA CANADA, Downsview, Ontario (Metro Toronto) Halifax
Montreal Winnipeg Saskatoon Edmonton Calgary Vancouver
representatives in principal cities of the world
Cable address—MINSAP Pittsburgh

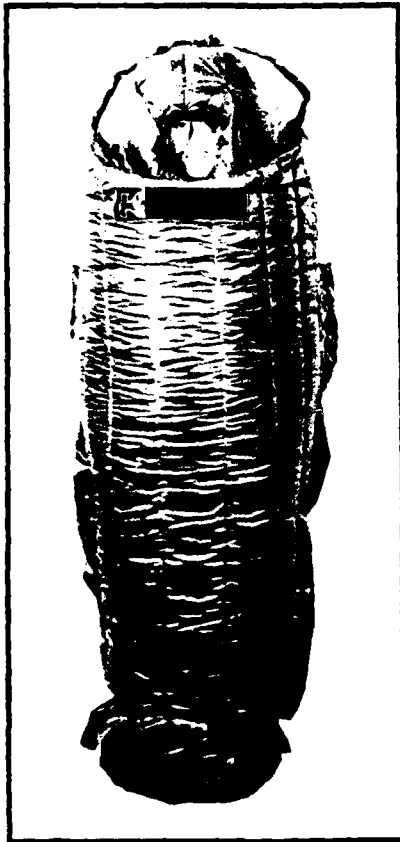


MSA SELF-RESCUER RESPIRATOR, PARTIALLY DISASSEMBLED
TO SHOW COMPRESSED WIRE PAD HEAT EXCHANGER

Stranded Bell Survival Equipment

Divers who are stranded in a bell or submersible without heat are doomed unless their body heat can be maintained. To provide such protection, Kinergetics and DUI market lines of bell survival equipment designed to prolong life in a stranded bell. Including such items as heavy sleeping bags and vests for conserving overall body temperature, they also provide small CO₂ scrubbers intended for one-man protection. Integral with these scrubbers are thermal regenerator elements which, it is claimed, conserve a great amount of the heat normally lost during exhalation.

STRANDED BELL DIVER SURVIVAL SYSTEM



SURVIVAL BAG

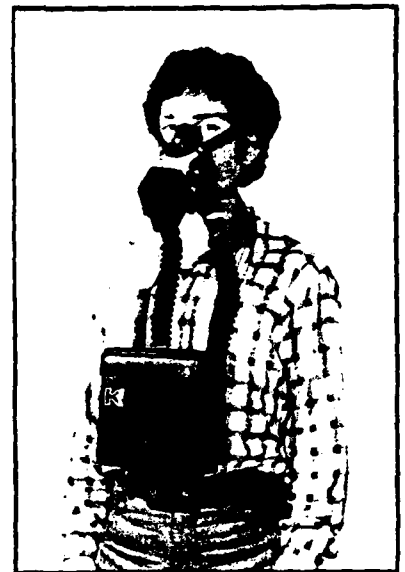
1. Provides protection for diver in cold helium environment.
2. Special back support that protects insulation from collapse allowing diver to sit or lay down with complete protection. This allows use in small bells.
3. Made of water resistant material.
4. Insulation is synthetic and does not absorb water.
5. Insulation system is designed for high efficiency in H_e/O_2 environment.
6. Comes vacuum-packed in nylon bag (vented).

TOTALLY PASSIVE, LIFE PROLONGING SURVIVAL MEANS
IN COLD HYPERBARIC H_e/O_2 ENVIRONMENT



SURVIVAL VEST

1. Provides insulation protection for all the vital areas, with special consideration for the head and neck.
2. Provides insulation protection for the CO_2 scrubber canister to conserve the reaction heat in the scrubber.
3. Provides protection for CO_2 scrubber and partial protection if diver has to get out of bag for any reason.
4. The face opening is designed in such a way to keep a warm layer of helium in front of the face to lower heat loss and increase comfort.



THERMAL REGENERATOR/SCRUBBER

1. Scrubs CO_2 from diver's outlet gas.
2. Conserves 95% of the respiratory heat loss at 300 M in a passive mode.
3. Provides an additional 20 watts of heat from the CO_2 scrubbing reaction.
4. Canister holds 5 lbs. of soda sorb for duration of over 24 hours.
5. Canister can be empty and refilled easily with standard soda sorb. soda lime, etc.
6. Thermal regenerator/scrubber is packed in separate nylon bag to allow easy use for backup scrubber without breaking into survival bag pack.

TECHNOLOGY FOR THE DIVING INDUSTRY





KINERGETICS INCORPORATED

6029 RESEDA BOULEVARD, TARZANA, CALIFORNIA 91356 • (213) 345-2851

KINERGETICS SURVIVAL SYSTEM

THE KINERGETICS SURVIVAL SYSTEM CONSISTS OF:

1. Survival vest which the diver slips on to protect his head and upper body and to provide insulation protection for retaining the heat in the soda cannister.
2. SURVIVAL BAG
 - Type 1 - Suspended Bag
 - Type 2 - Mattress supported bag - the diver gets into this bag and closes it up around the top of the vest. This bag has a special mattress included that the diver blows up to prevent the insulation from collapsing when he is sitting or laying in the bag.
3. THERMAL REGENERATOR/SCRUBBER

This unit provides passive protection from respiratory heat loss and scrubs the exhaled gas. The thermal regenerator is 95% efficient at 300 M on He/O_2 . The diver puts on this unit prior to the survival vest by slipping it over his neck and attaching the oral nasal mask.

SYSTEM TEST TO DATE:

1. Commerical Diving Center, Wilmington, California in November 1979: one diver in He/O_2 at 66 FSW with the chamber at 2°C for 24 hours.
2. Norwegian Underwater Institute, Bergen, Norway in January 1980: the test at NUI was at 150 M with the chamber at 4°C . The test plan at NUI was for the diver to stay 12 hours in the system and if he was stable to remove the thermal regenerator and see how long he could go without it. The diver entered the chamber and stayed in the 4°C without the survival system for approximately 7 minutes. His rectal temperature went from 37° to 36° in this time. The diver put on the survival system, within 3 hours his rectal temperature was back up to 37°C . During this time the diver took off the thermal regenerator because he said the gas temperature was hot. The temperature from the regenerator was 38 to 40°C . The diver said that when he was breathing the cold gas he felt fine for approximately one hour, then he began to shiver. At this time he would use the regenerator again for about 1/2 hour until the shivering stopped. The diver continued on and off the regenerator for 9 hours. Then he did not use the regenerator until he quit the test. During this time his rectal, head, and foot temperature rapidly went down. The diver stayed in the survival suit for 10 1/2 hours.

WHY DID THE DIVER QUIT?

In part it was because his legs were extremely uncomfortable both from the cramped position and the cold. At 9 hours, with his trunk and upper body relatively comfortable he felt that he was doing fine and that there would be no crucial reason to quit for many hours. He thus decided to leave the breathing protection device off. The diver said there was no doubt in his mind that he could have stayed for 12 hours more.

The complete test report is available from Norwegian Underwater Institute, Bergen Norway.

Specifications subject to change without notice.

Form No. 01-091

February 25, 1980



DUI-HAMILTON CO₂ SCRUBBER REGENERATOR

TESTED — SIMPLE — MEETS SPECIFICATIONS — LOW PRICE

This is a new highly versatile piece of equipment that has many applications; these include:

Treatment or Prevention of Hypothermia.

A backup system for:

- Diving Bells
- Submarines
- Saturation Deck Chambers
- Surface Air Decompression Chambers
- Use in high CO₂ atmospheres.

SPECIAL FEATURES

- Small in size - simple to use.
- Comfortable to wear.
- Light weight - rugged construction.
- Temperature controllable.
- See through design.

SPECIFICATIONS:

- Canister - inside 1 3/4" x 5 1/2" x 9 1/4"
- SodaSorb 2.9 to 3 pounds (with a good packing job)
- Mask and Canister overall 18 inches length.
- Duration: Minimum 12 hours at normal rate.



The DUI-HAMILTON team has produced a highly professional design which employs several very unique approaches. They include:

- A special design which eliminates almost 50% of the dead space.
- Highly versatile - can be used in 3 modes depending on application.
- To-Fro for hypothermia and cold applications. By installing or changing direction of non-return valves it can scrub inhale only, or exhale only.
- See through design permits monitoring of CO₂ absorbent condition.
- Oral nasal and support head harness permits comfort that won't dislodge accidentally.
- The user can adjust the heat output.
- Fill caps are filled with SodaSorb and are spring loaded to compensate for canister settling.
- There is a saliva and condensation trap and removal system.
- Canisters have a unique reusable storage bag which prolongs the storage life of the canister.
- Design tested and proved in NUI Polar Bear tests.

now available with a single 24 hr. canister



*Customer Service assistance in evaluating proposed applications is available;
For additional information please contact any of our sales offices listed below:*

DIVING UNLIMITED INTERNATIONAL, INC.

1148 Delevan Drive • San Diego, CA 92102 • Phone: (714) 236-1203 • Telex: 697971

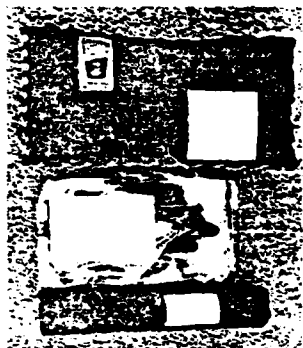
DUI LIMITED • Advance Unit 8

Farburn Industrial Est. • Dyce, Aberdeen • Phone: (224) 724093 • Telex: 739130

All equipment and specifications are subject to change without notice.



DUI POLAR BEAR



The DUI Polar Bear system provides diving personnel under hyperbaric conditions with passive protection in the event of loss of active chamber or bell heating. All avenues of body heat loss have been evaluated and optimum conservation measures applied. The system is based on the successful tests of Project Polar Bear.



FEATURES

- Design tested and proven at NUI Polar Bear tests.
- Small storage requirements.
- Meets current specifications.
- Low Price.

SPECIFICATIONS

Storage and Mounting. The sleeping bag - vapor barrier - parka or vest and hood - booties urine collection system are all stored in a very unique DUI designed heavy rubberized compression pillow. This unit is field repackable and can be mounted in the bell with velcro hooks glued to the bell wall or through the strap slots provided, or by attaching through the grommets; it will form to meet most shapes or storage requirements.

Insulator Mattress Storage. The insulation mattress is stored by rolling very tightly and storing in a heavy rubberized tube.

SYSTEM COMPONENTS.

Scrubber/Regenerator. Uses one DUI-HAMILTON scrubber/regenerator with an extra canister. Specifications for this component are listed on the reverse side of this sheet.

Sleeping Bag - Overkill? The bag chosen is the highest quality bag available. It has a - 25°F (- 32°C) rating with rigid documentation to verify rating. It is made of Polargard insulation. It is sized for a 6'4" tall man - loft 9'5" - length 89". It features double zipper flaps, a draw collar, and hood. The long term effect of compression is unknown to anyone at this time. We are allowing for both the woolybear and some compression in this design. This unit has 35% more insulation than the unit tested at NUI.

Bag Size. This bag is the largest size manufactured. A super extra large size can be made for an extra charge and minimum quantity order.

Vapor Barrier. The bag is equipped with a very heavy plastic bag to keep water from the bilge of the bell from entering the bag system. It also acts as a barrier to help keep the moisture from migrating from the diver outward.

Parka or Vest with Hood. The choice of a vest with hood or parka with arm protection is provided at customer's choice.

Isolation Mattress. This inflatable mattress is placed between the diver and the bell. It has an internal packing to prevent convective currents. It can be used in or outside of the vapor barrier bag according to best individual application. Size 20" x 72" x 1 1/2".

Urine Collection. A supply of special plastic sponge bags is supplied. These are similar to the ones used in Navy deep submersibles.

Boots. Extra protection for the feet is provided with PolarGard Boots.

1 Storage Pillow 13" x 5 1/2" x 24"

1 Mattress 20" x 4 3/4"

1 Canister 12" x 5 1/2" x 1 3/4"

1 Mask & Canister 18" x 5 1/2" x 1 3/4"

All equipment and specifications subject to change without notice.

**PASSED
NUI
300 M
TEST**

A Respiratory Heat Exchanger for Runners

Some distance runners experience various forms of respiratory distress because of breathing cold air at high rates in winter. To alleviate this problem, a device is marketed to cure the ill. Although the degree of comfort acceptability may be doubtful, the principle is sound and the concept could be used, with some modification, in diver breathing apparatus.



NOW YOU CAN IGNORE COLD AIR!

EVEN AT 30° BELOW,
YOU CAN ALWAYS
BREATHE WARM AIR

Designed by a physician who jogs the year around, the TropicAir Breathing Aid uses both the heat from exhaled air and body heat to warm the outside air before you inhale it. No chemicals, no batteries ... just a natural heat-exchange taking place in a design that is so unique it has been awarded a U.S. Patent. The TropicAir is lightweight, easy to use, and comfortable. Best of all, it prevents pain from cold-air-induced bronchospasms (the sensation of having your breath taken away). Even at temperatures as low as -30°, you can breathe clean, fresh +50° air...and keep training all Winter long!

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handling (Missouri residents please add \$.92 sales tax).

☐ Send your free brochure as soon as possible

NAME _____

STREET ADDRESS _____

CITY/STATE/ZIP _____

Send to: TropicAir, Dept. A, P.O. Box 146, Smithville, MO 64089

FUTURE IMPROVEMENTS

The present method of using a heat exchanger in the gas line has one outstanding virtue - it is versatile. One heater can serve many types of helmets and masks. On the negative side, it is wasteful of heat and cannot always provide the level of heat required unless efforts are made to reduce losses between heater and helmet, by such as hot-water shrouding devices.

The obvious cure for the inefficiencies of the present system is to mount the heat exchanger directly on the helmet or mask, so that the gas is heated as it enters. Present heat exchanger designs are small, and have shown that they can be packaged in tight places. Any helmet or mask intended for use in deep diving ought to have a heat exchanger mounted in its inlet passage as a matter of course. The heat may not be needed in all cases, but it will be there when it is needed.

In the case of band masks or other apparatus employing oral-nasal inserts, a regenerative exchanger should be developed to fit inside the oral-nasal cup. Such an exchanger might be configured like an ordinary dust mask, such as is worn in many dry workplaces where inhalation of dust or transfer of germs is undesirable. If made of metal screen, it would exchange heat during respiration and mitigate somewhat the loss of heat from the diver. Of course, it could not be so large as to require more than the present 50cc or so of allowable dead space, but it is probable that a reasonably effective device could be made.

Both of these proposed improvements to the present state of the art are desirable, and development costs are likely to be low. It is recommended that both be developed so that field evaluation of their effectiveness can proceed.

